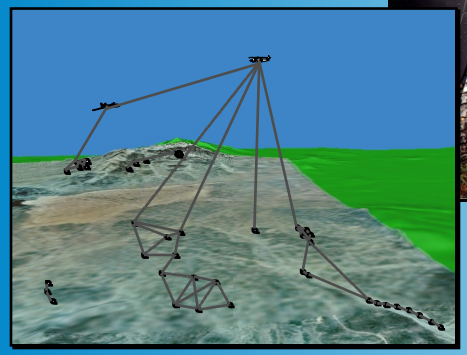
Collaborative Technology Alliance



Communications & Networks

Dr. John W. Gowens
ARL Cooperative Agreement Manager

Telcordia Technologies

Dr. Ken Young
Consortium Manager, Telcordia Technologies

Communications and Networks Collaborative Technology Alliance

Consortium Partners

- Telcordia Technologies (Lead)
- Network Associates
- BBN Technologies
- General Dynamics
- BAE Systems
- Georgia Tech
- U of Maryland
- U of Delaware
- Princeton
- Johns Hopkins
- Morgan State
- CCNY

Objectives

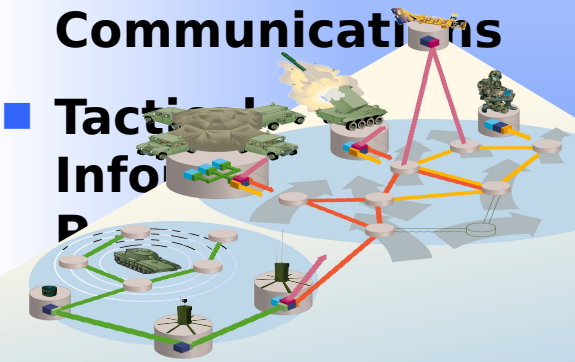
Technologies that enable a fully-mobile, fully-communicating, agile, situation-aware, and survivable lightweight force with internetted C4ISR systems.

Large, heterogeneous, wireless communication networks that:

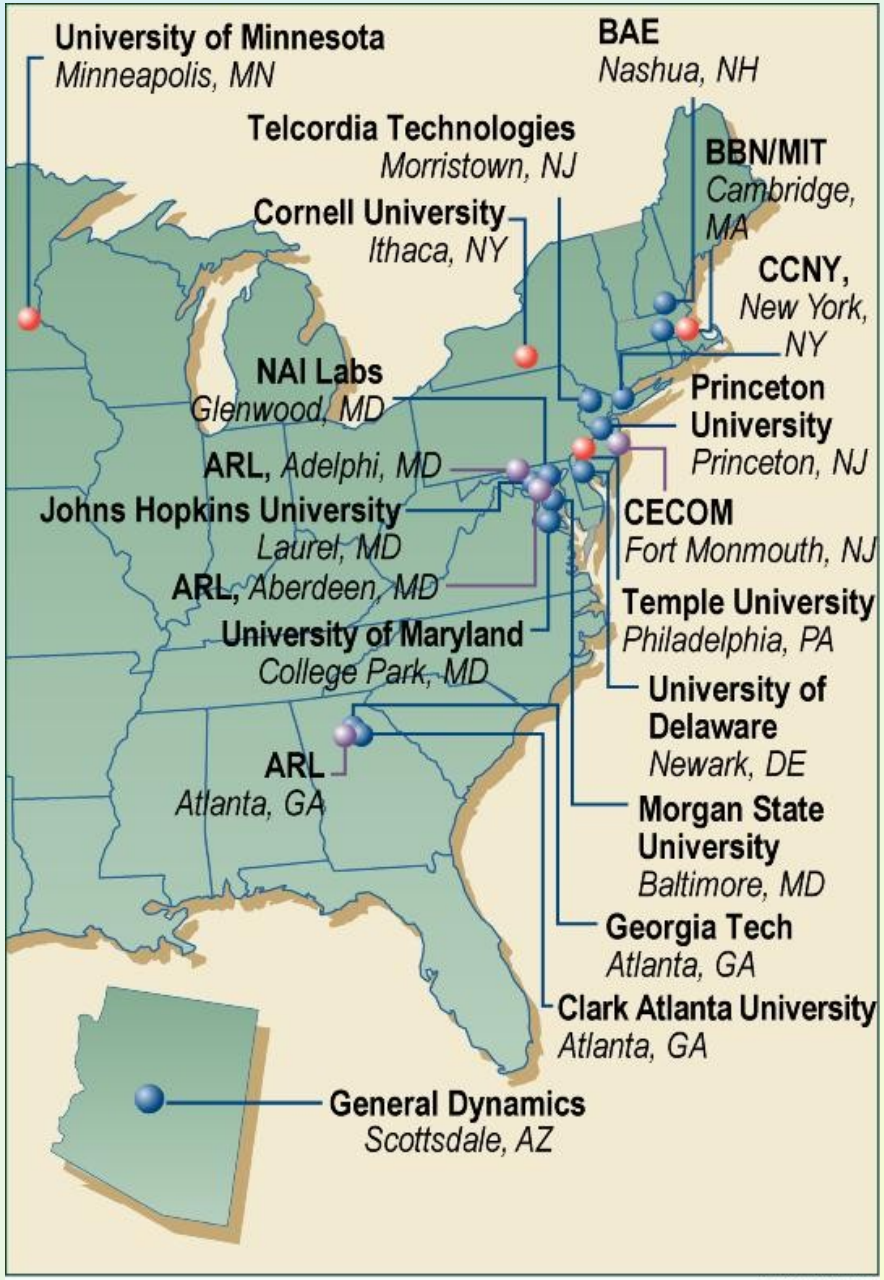
- **Operate while on-the-move with a highly mobile network infrastructure**
- **Under severe bandwidth and energy constraints**
- **While providing secure, jam-resistant communications in noisy hostile wireless environment**

Technical Areas

- **Survivable Wireless Mobile Networks**
- **Signal Processing for Comms-on-the-Move**
- **Secure Jam-Resistant Communications**
- **Tactical Information**



Member Locations



Communication and Networks Collaborative Technology Alliance

PM: Telcordia Technologies, Dr. Ken Young

CAM: ARL, Dr. John W Gowens II

Survivable Wireless Mobile Networks

Telcordia, Dr. Ken Young
ARL, Mr. Hal Harrelson

Highly Efficient & Robust Subnet Organization

BBN, Dr. J. Redi
UDel, Dr. E. Lloyd

Autonomous Internetworking

Telcordia, Dr. A. McAuley
JHU, Dr. I-J. Wang

Efficient, Reliable End-to-End Networking

Telcordia, Dr. M. Fecko
UDel, Dr. P. Amer

QoS-Driven Network Management

Telcordia, Dr. W. Chen
CCNY, Dr. T. Saadawi

Signal Processing for Comms-on-the-Move

Telcordia, Dr. Joe Liberti
ARL, Dr. Ananthram Swami

Multi-User Detection

BAE, Dr. R. Learned

MIMO and Space-Time Coding

Telcordia, Dr. J. Liberti
UDel, Dr. X. Xia

Cross-Layer Design and Novel Concepts

BAE, Mr. M. Landel
Ga Tech, Dr. M. Ingram

Secure Jam-Resistant Communications

BAE, Mr. Matt Landel
ARL, Dr. Brian Sadler

Waveform Design

GD, M. S. Chuprun
Ga Tech, Dr. G. Stüber

Array Processing and Interference Rejection

GD, Mr. C. Bergstrom
UDel, Dr. G. Arce

Frequency-Hopping Systems

GD, Mr. J. Kleider
UDel, Dr. C. Boncelet

Tactical Information Protection

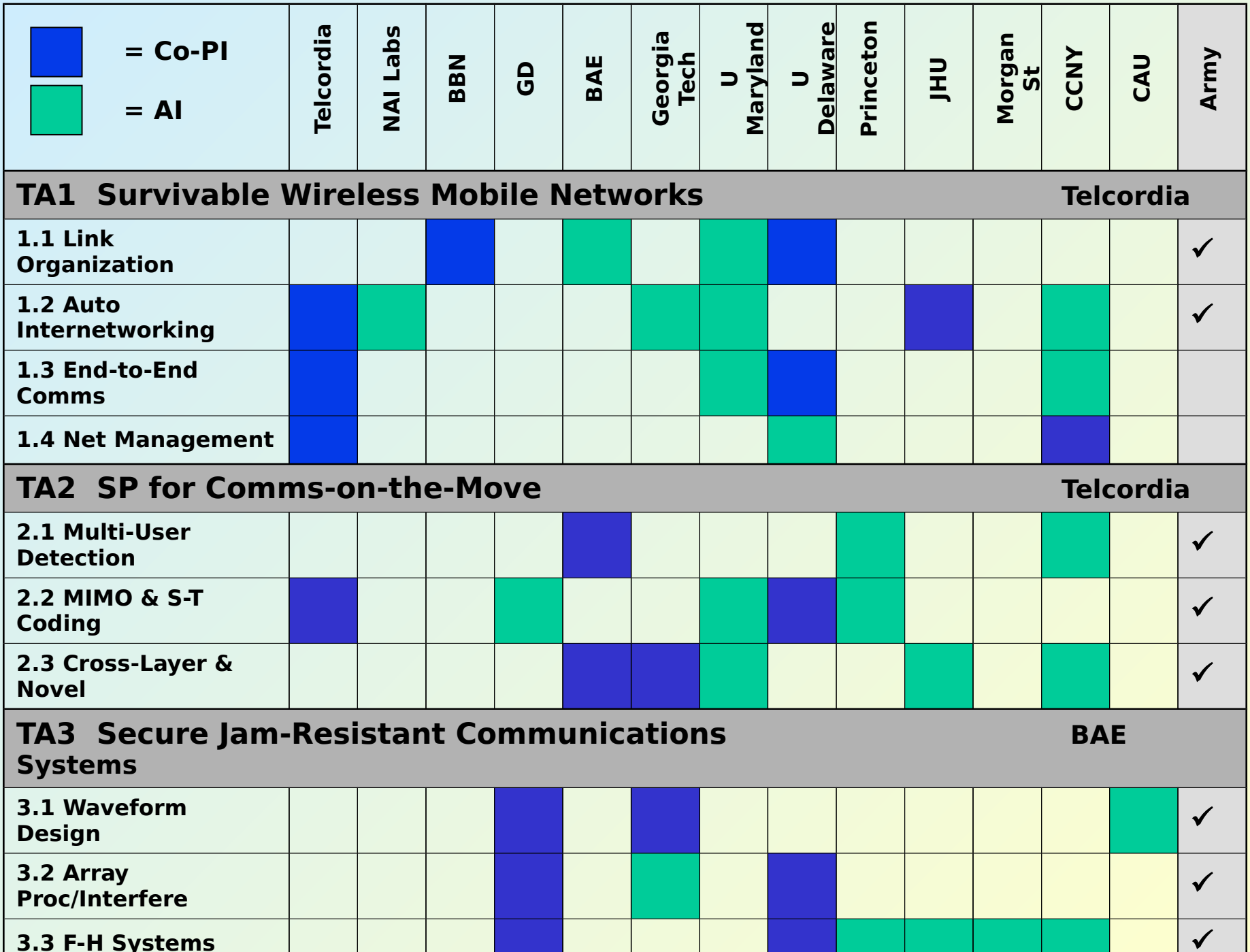
NAI, Mr. Dave Balenson
ARL, Mr. Greg Cirincione

Highly Efficient Security Services and Infrastructure

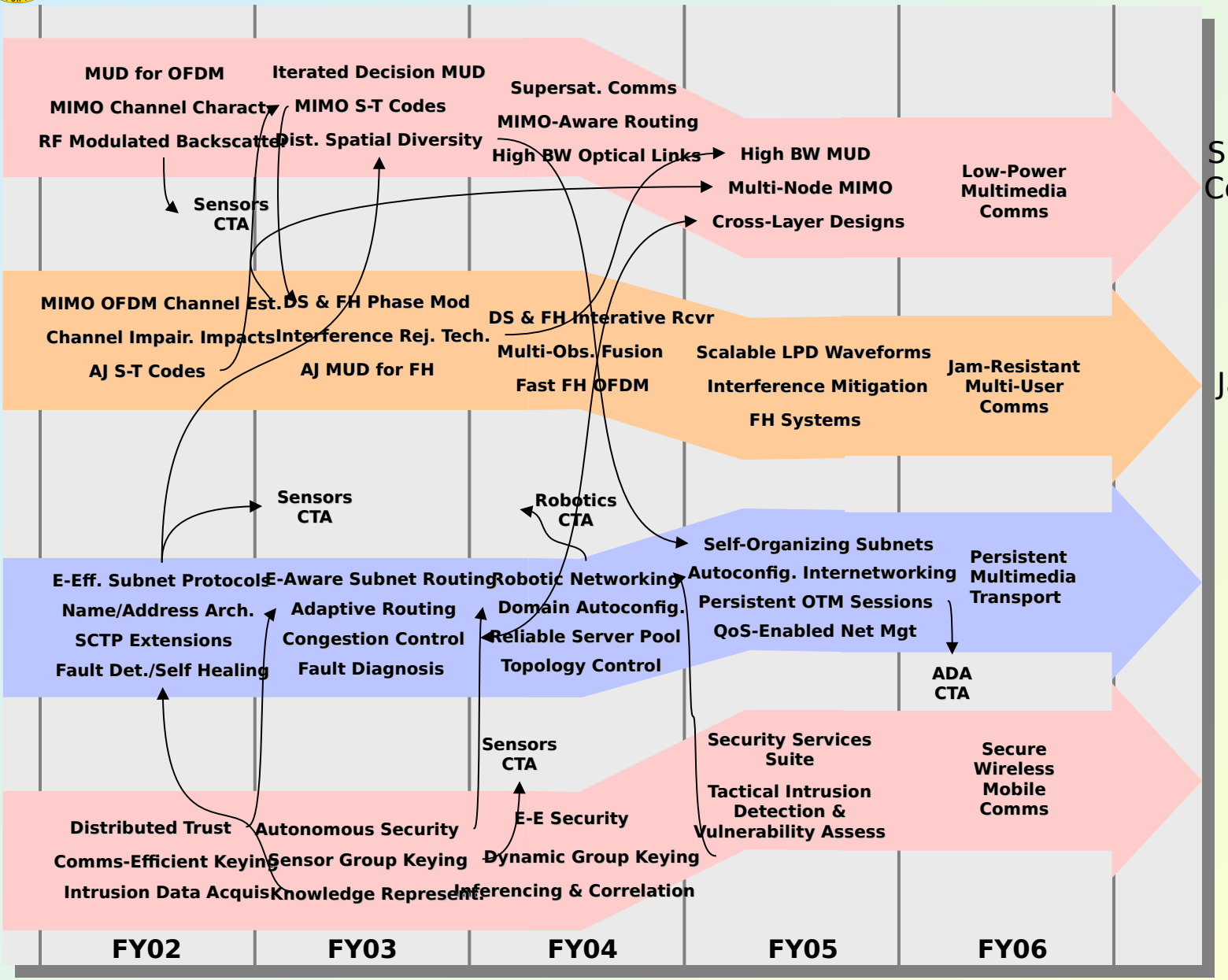
NAI, Mr. D. Carman
UMd, Dr. J. Baras

Tactical Intrusion Detect./Vulnerability Assessment

Telcordia, Mr. M. Little
Ga Tech, Dr. J. Cannady


= Co-PI
= AI
Telcordia
NAI Labs
BBN
GD
BAE
Georgia Tech
U Maryland
U Delaware
Princeton
JHU
Morgan St
CCNY
CAU
Army
TA1 Survivable Wireless Mobile Networks
Telcordia
1.1 Link Organization
1.2 Auto Internetworking
1.3 End-to-End Comms
1.4 Net Management
TA2 SP for Comms-on-the-Move
Telcordia
2.1 Multi-User Detection
2.2 MIMO & S-T Coding
2.3 Cross-Layer & Novel
TA3 Secure Jam-Resistant Communications Systems
BAE
3.1 Waveform Design
3.2 Array Proc/Interfere
3.3 F-H Systems

Technology Roadmap



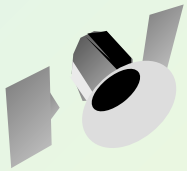
Communications for Future Combat Systems

Motivation: **To Simultaneously and Reliably Achieve**

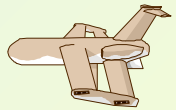
- **High Data Rates for Collaborative C⁴ISR (Network-Centric Operations)**
- **Low Probability of Detection**
- **Robustness to Jamming**
- **Communication-on-the-Move in Highly Dynamic Environments**

Objective: **A fully mobile and lightweight force with internetted C⁴ISR with**

- **Mobile, ad hoc networks capable of operating with extreme LPD and jamming resistance**
- **While carrying real-time traffic for positive robotic and fire control**



Small Unit UAV



Robotic Indirect Fire

Network Centric

Robotic Sensor

Robotic Direct Fire

C2/Troop Carrier (Dismounts)

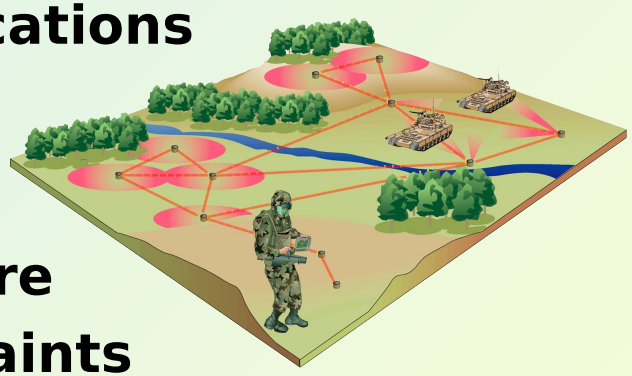
Future Combat Systems Communications Notional Approach

A fully mobile and lightweight force with internetted C^4ISR

- **High-band communications to simultaneously achieve high data rates, LPD, and A/J**
- **Low-band communications to enable interoperability and operate when direct line-of-sight is unavailable due to terrain, foliage, or weather**
- **Directional antennas to meet survivability/throughput requirements**
- **Airborne assets to augment connectivity in highly dispersed operations especially in complex terrain**
- **Diverse communications requirements:**
  - **Command and control/situational assessment data among all nodes**
  - **Sensor data distribution between UAVs, UGSs, and robotics**
  - **Fire control between vehicles and weapons platforms**
- **Many elements will be unmanned with significant risk of capture**

Survivable Wireless Mobile Networks (TA1)

Objective: **Dynamically self-configuring wireless network technologies that enables secure, scaleable, energy-efficient, and reliable communications**



Challenges:

- **Scalability to thousands of nodes**
- **Highly mobile nodes and infrastructure**
- **Severe bandwidth and energy constraints**
- **Decentralized networking and dynamic reconfiguration**
- **Accommodation of high bit-error-rate, wireless networks**
- **Seamless interoperability**

Research Tasks:

1. **Highly Efficient and Robust Subnet Organization**
2. **Autonomous Internetworking**
3. **Efficient, Reliable End-to-End Networking**
4. **Quality-of-Service Driven Network Management**

Survivable Wireless Mobile Networks (TA1)

Research Tasks:

1.Highly Efficient and Robust Subnet Organization

- Energy-Efficient Media Access and Topology Control
- Energy-Aware Subnet Routing
- Cross-Layer Coupling For Effective and Enhanced Communications

2.Autonomous Internetworking

- Naming and Addressing for Mobile Networks
- Autoconfiguring Domains for Mobile Networks
- Autonomous Internetworking Security
- Dynamic and Adaptive Routing

3.Efficient, Reliable End-to-End Networking

- Persistent On-the-Move Sessions
- Reliable Server Pooling
- Bandwidth Estimation
- Congestion Control

4.Quality-of-Service Driven Network Mg

- Adaptive Bandwidth Management

Consortium Partners

- Telcordia Technologies
- BBN
- U Maryland
- U Delaware
- CCNY
- BAE Systems
- NAI Labs
- Johns Hopkins
- Georgia Tech
- Temple

TA1 FY01-02 Accomplishments

Highly Efficient and Robust Subnet Organization

- Designed and began evaluation of mechanism to use set of dynamically selected backbone nodes to synchronize sleep intervals among neighboring nodes
- Developed energy-efficient routing and transmission scheduling methods for directive antennas and energy-efficient neighbor discovery protocols

Autonomous Internetworking

- Invented a new naming and addressing approach; decouples application names from IP addresses to better support mobility, multi-homing and autonomous operation
- Developed formal models for routing protocols to systematize performance evaluation in mobile ad hoc networks

Efficient, Reliable End-to-End Networking

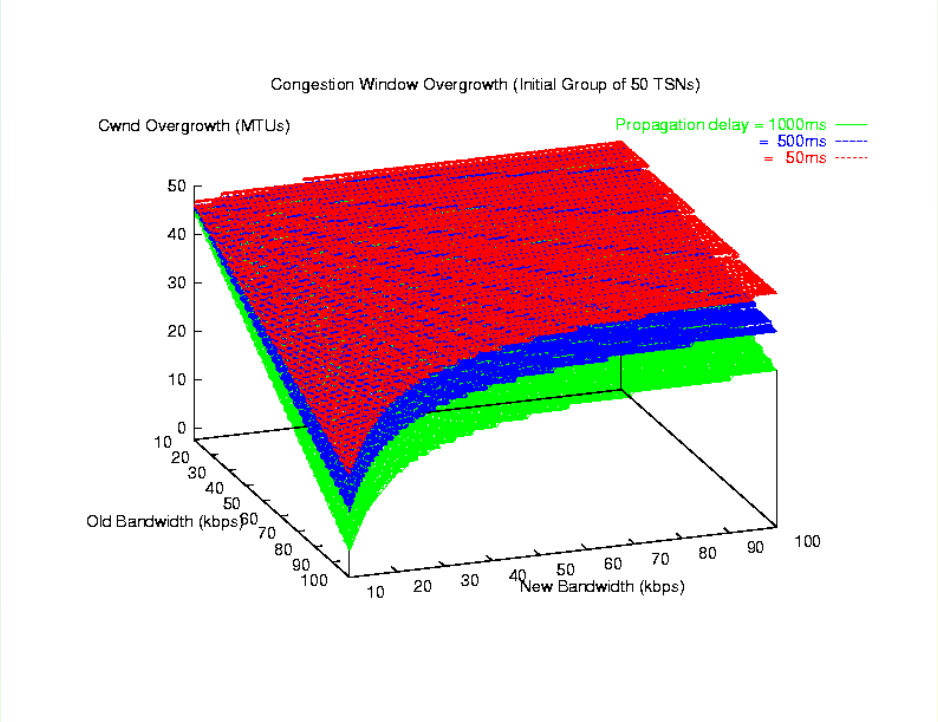
- Contributed Internet Draft: “SCTP Extension for Dynamic Reconfiguration of IP Addresses and Enforcement of Flow and Message Limits”
- Designed two candidate mechanisms for handling lost SCTP messages to allow persistent on-the-move sessions

Quality-of-Service Driven Network Management

- Initial design of wireless root cause analysis engines; identified an appropriate alarm model and began working details of the elements of the alarm model
- Designed and simulated the Delay Differentiation with Earliest-Deadline-First (DD-EDF) QoS architecture; much improvement in end-to-end/per-hop average queueing delay performance while

Improved Transport Layer Congestion Control

- Explore new transport layer alternatives for survivable wireless mobile networks
- Split Fast Retransmit Changeover-Aware Congestion Control (SFR CACC) algorithm submitted as IETF Internet Draft
- Exploit transport layer (e.g., SCTP) multi-homing for uninterrupted end-to-end communication
- Significantly enhances transport layer's ability to support persistent on-the-move sessions for FCS networks



Signal Processing for Communications-on-the-Move

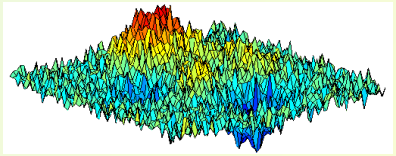
Objective: **Signal processing techniques to enable reliable low-power multimedia communications among highly mobile users under adverse channel conditions**

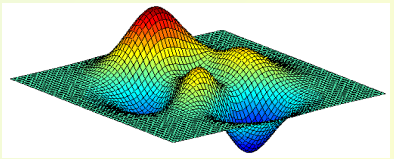
Challenges:

- **Highly mobile nodes and infrastructure**
- **Highly diverse and dynamic channels and network topologies**
- **Bandwidth, spectrum, and energy constraints**
- **Mobile, high-speed, secure communications**
- **Low complexity transceiver design**

Research Tasks:

1. **Multi-User Detection for increased channel capacity while overcoming interference**
2. **MIMO & Space-Time Coding for increased robustness in variable, harsh environment**
3. **Cross-Layer Design & Novel Concepts**





Signal Processing for Communications-on-the-Move (TA2)

Research Tasks:

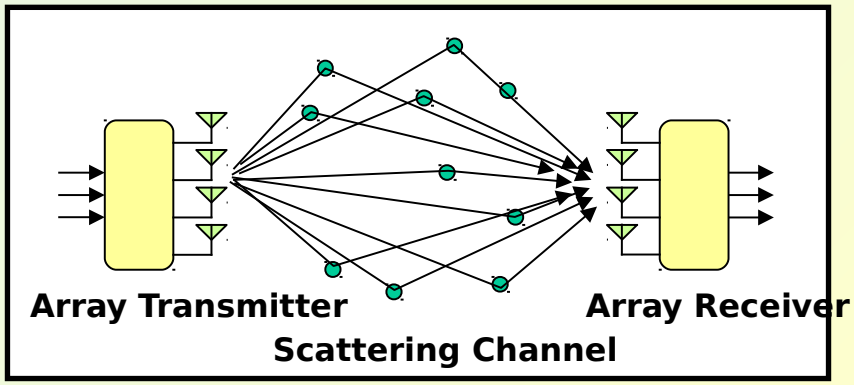
1. **Multi-User Detection (MUD)**
   - Multi-User Detection
   - Supersaturated Multiple Access
   - Frequency-Hopping Generalized Multi-Carrier CDMA

2. **Multi-Input Multi-Output (MIMO) and Space-Time Coding**
   - MIMO Link Enhancement
   - Adaptive Multi-Node Optimization

3. **Cross-Layer Design and Novel Concepts**
   - Cross-Layer Design

Consortium Partners

- BAE Systems
- Princeton
- U Maryland
- Telcordia
- General Dynamics
- U Delaware
- Georgia Tech
- Johns Hopkins
- CCNY



TA2 FY01-02 Accomplishments

Multi-User Detection

- Formulated Multi-User Detection strategy for Frequency Hopping signals, and established bounds on performance showing 15-100 fold capacity improvement over conventional techniques.
- Developed iterated decision, “Turbo-MUD” approach for FH MUD.

Multi-Input Multi-Output Systems

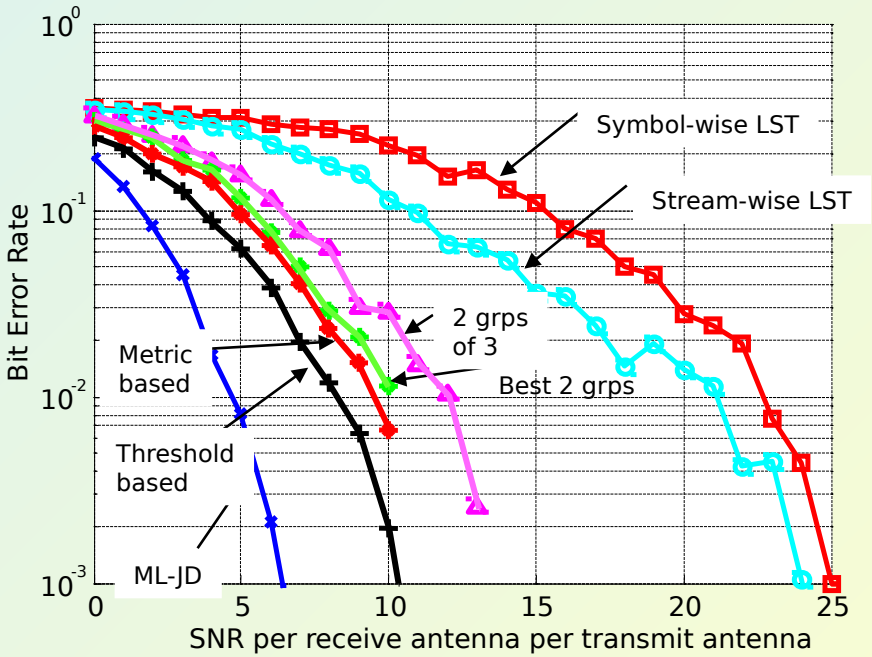
- Developed, modeled and demonstrated hybrid Space-Time Trellis Coded OFDM MIMO with a Maximum Likelihood-Joint Detection receiver, and showed major improvement over Layered Space Time approaches (>12 dB over the air, 16 dB in theory for a 4x4 system). Showed that this approach provides great robustness to loss of channel rank.
- Developed Generalized Variable Quality of Service (GVQoS) approach for efficiently packing multiple data streams into OFDM waveforms, working on extensions to MIMO-OFDM.

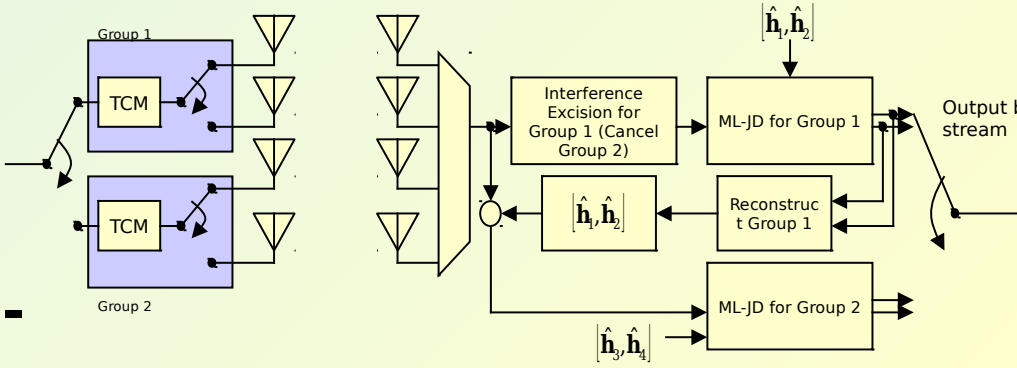
Cross Layer Design and Novel Concepts

- Modeled MIMO backscatter approach for interrogating sensor fields from airborne platform.
- Developed simple effective hop detection technique based on spectrogram entropy analysis; including two multi-user localization approaches and a dynamic programming high-resolution tracking algorithm for a single FH signal.
- Modeled atmospheric turbulence for high bandwidth, short range optical links.

Hybrid MIMO OFDM with ML Detection – Modeling and Experiments

- **Developed new approaches to MIMO broadband NLOS comms, showed major improvement in SNR performance and robustness to channel rank deterioration compared with LST approaches.**
- **Developed metrics for dynamic sub-group selection.**
- **Implemented over-the-air demonstration of Hybrid MLJD over non-LOS channels using a four element transmitter and 8-element receiver.**





Secure Jam-Resistant Communications

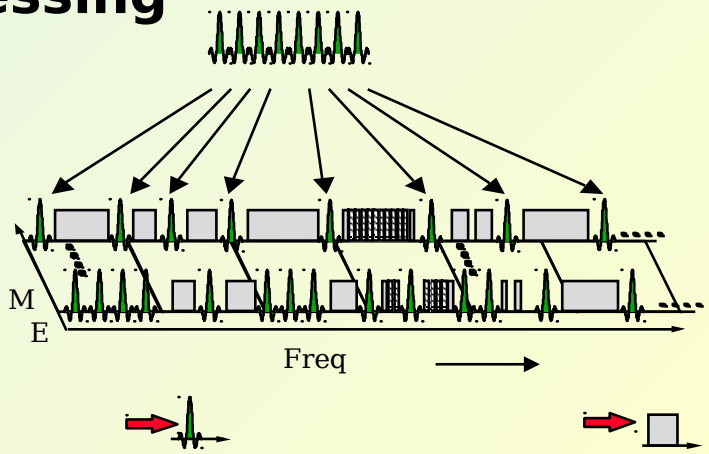
Objective: **Secure, jam-resistant, multi-user communications effective in noisy/cluttered and hostile wireless environments enabling LPD and LPI on-demand**

Challenges:

- **Multi-user and co-site interference**
- **Quality-of-service, LPI, and LPD requirements**
- **Electronic warfare and nearby jamming threats**
- **Transceivers differ in signal processing complexity**

Research Tasks:

1. **Waveform and Packet Design**
2. **Array Processing, Interference Mitigation, and Spectrum Reuse**
3. **Frequency-Hopping Systems for Robustness and Security**



Secure Jam-Resistant Communications (TA3)

Research Tasks:

1.Waveform and Packet Design

- Waveform Design
- Synchronization and Channel Estimation
- Coding for OFDM
- Packet Design

2.Array Processing, Interference Mitigation, and Spectrum Reuse

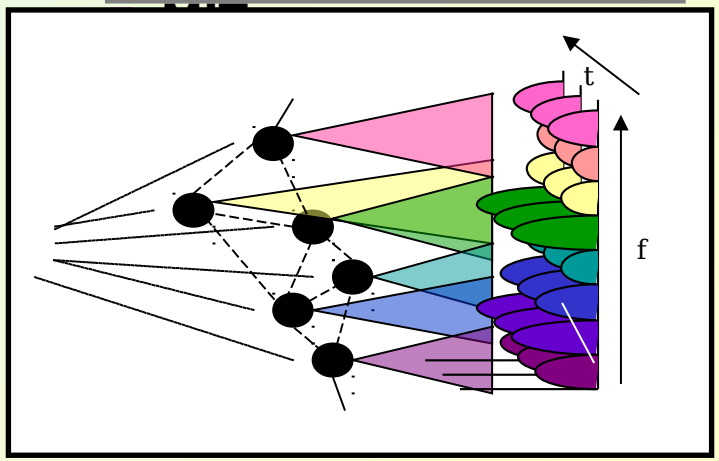
- Re-configurable Aperture Array Processing
- Blind Signal and Interference Separation

3.Frequency-Hopping Systems

- Anti-Jam Waveform Design
- Anti-Jam Multi-User Detection
- Adaptive Integrated Anti-Jam Systems

Consortium Partners

- BAE Systems
- General Dynamics
- Georgia Tech
- Princeton
- Clark Atlanta
- Morgan State
- U Delaware
- CCNY
- U Maryland
- Johns Hopkins



TA3 FY01-02 Accomplishments

Waveform and Packet Design

- Developed a computationally efficient PAPR algorithm for SS/OFDM; achieves 7 dB range or fade margin improvement for transceivers with a fixed power amplifier output; minimal impact on adjacent channel performance and LPD properties.
- Designed an iterative serial concatenated CPM (DS/SS-SCCPM) system using jammer state information
- Implemented the Quaternary Direct-sequence System (QDS) with complex modulator and complex correlator; uses complex-valued quaternary sequences as spreading sequences

Array Processing, Interference Mitigation, and Spectrum Reuse

- Developed a new concept of complex linear combination of complex weighted medians (LCWM) for array-of-array processing; being used as the basic structure of multiple architectures
- Developed iterative fast beamforming algorithm to detect the direction of arrival for wideband signals

Frequency-Hopping Systems

- Developed robust synchronization methods for fast hopping and bandwidth efficient FH-OFDM systems
- Designed a testbed to implement a traffic-based TDMA over FHSS system; implemented on-demand routing at MAC level; investigated the Scatternet structure optimization and scheduling

Robust Synchronization Methods for Fast Hopping and Bandwidth-Efficient FH-OFDM

Objective: **Scalable spectrally efficient techniques to support jam-resistant communications**

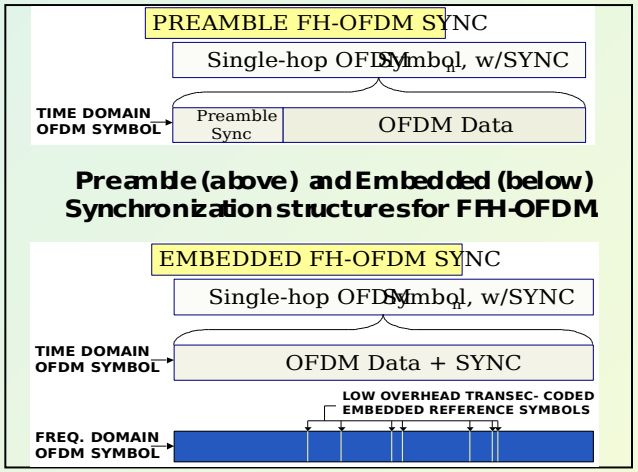
- Robust to Multi-Path
- Adaptive Optimization to Threat and Channel Dynamics

Issues: **Demands for faster hop rates induce a requirement for shorter preamble lengths**

- Receiver probability of missing signal detection (P_{miss}) increases
- Probability of false detection of the signal of interest (P_{false}) increases

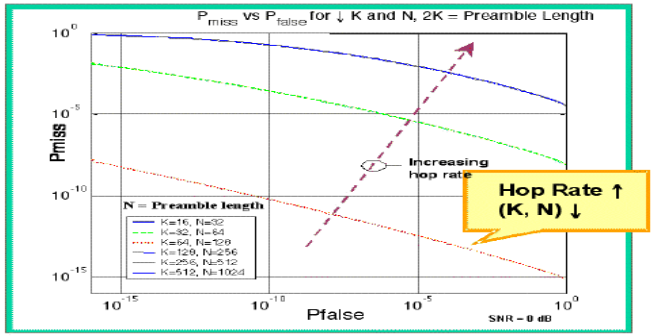
Results: **Method of synchronizing can have a profound effect on the hop rate capability and bandwidth requirements**

- **ROC analysis to provide design guidelines for maximum FFH-OFDM system hop rates**
- **Hop rates and capacity for FFH-OFDM can be maximized by applying embedded (semi-blind) sync methods**
  - Hop Rate analysis shows our embedded sync approach can improve FFH-OFDM system hop rates
  - Preamble sync provides up to 40% increase in

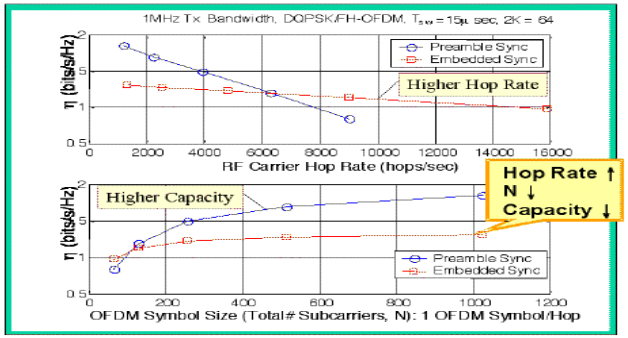


Preamble (above) and Embedded (below) Synchronization structures for FFH-OFDM

Synchronization Performance Comparison



ROC Curves Suggest a Maximum Hop Rate Limit



Preamble Synch vs Embedded Sync FH-OFDM Capacity

Tactical Information Protection

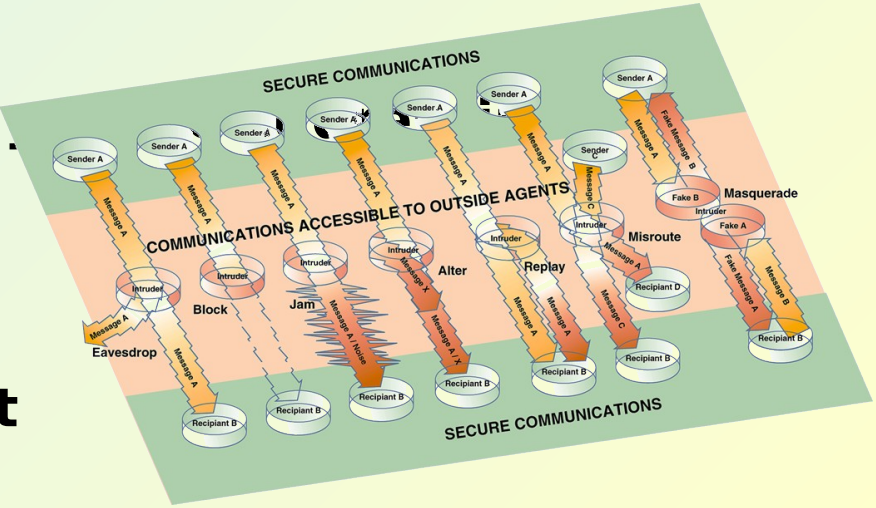
Objective: **Technologies that provide automated, scaleable, efficient, adaptive, and secure information protection in wireless, multi-hop, self-configuring networks**

Challenges:

- **Severe bandwidth, energy, and node capture constraints**
- **Accommodation of high bit-error-rate, wireless networks**
- **Lack of concentration points where network traffic can be analyzed**
- **Information protection with d**

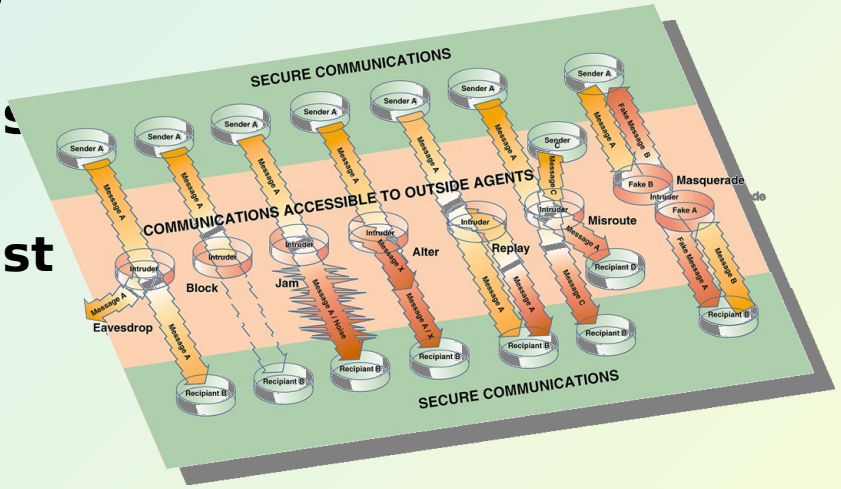
Research Tasks:

1. **Highly-Efficient Security Services and Infrastructure**
2. **Tactical Intrusion Detection and Vulnerability Assessment**



Tactical Information Protection (TA4)

Research Tasks:



1. **Highly-Efficient Security Services and Infrastructure (HESSI)**
   - Autonomous and Distributed Trust Establishment
   - Dynamic Group Keying
   - Noise-Tolerant, Energy-Efficient Security Mechanisms

2. **Tactical Intrusion Detection and Vulnerability Assessment (TIDVA)**
   - Event Data Acquisition and Dissemination for Tactical Environments
   - Tactical Intrusion Knowledge Representation Using Conceptual Structures
   - Inferencing and Correlation for Tactical Environment Attack Detection

Consortium Partners

- NAI Labs
- Telcordia Technologies
- BAE Systems
- Georgia Tech
- U of Maryland
- U of Delaware
- Morgan State
- CCNY

TA4 FY01-02 Accomplishments

Highly Efficient Security Services and Infrastructure (HESSI)

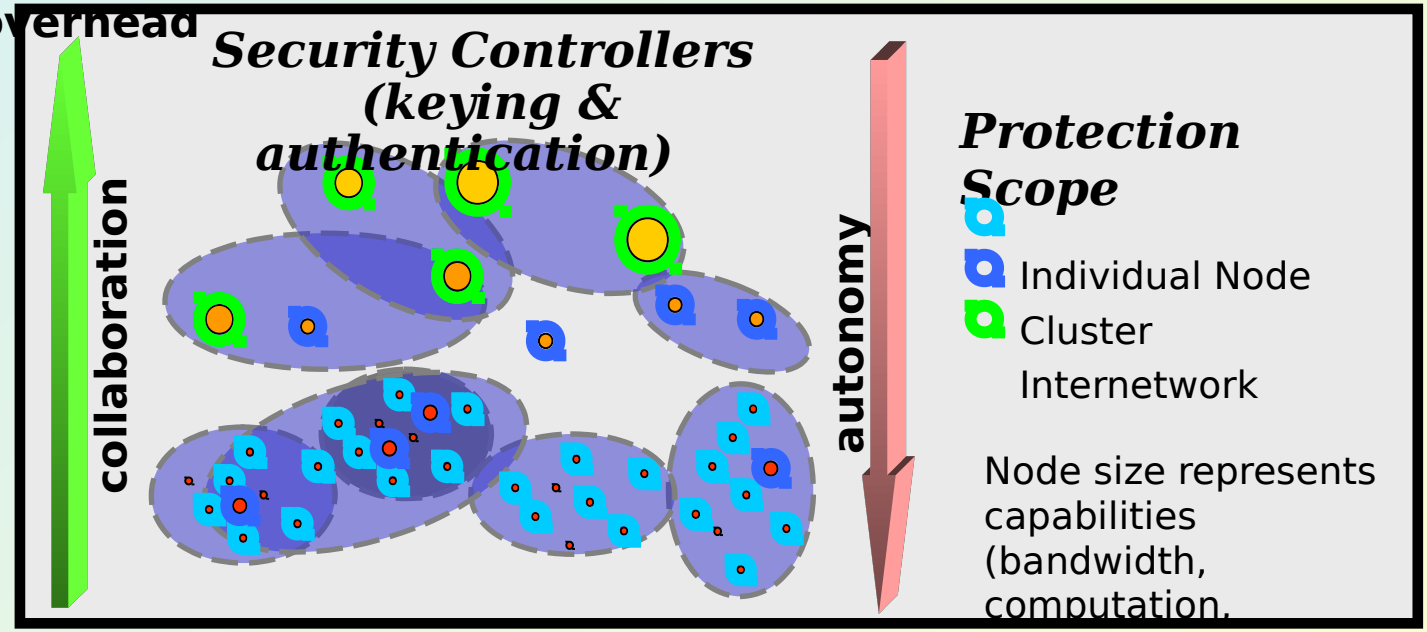
- Developed approach for using “swarm intelligence” to autonomously distribute trust credentials without reliance on central authority
- Developed new protocol combining conference and identity-based group keying to conserve energy through reduced communications overhead
- Developed, implemented, and evaluated a tamper detection mark for authenticating mobile Java classfiles without increasing file size
- Developed method of authenticating packets at physical layer based on correct PN code sequence correlation to reduce packet size AND increase reliability

Tactical Intrusion Detection and Vulnerability Assessment (TIDVA)

- Established novel approach to incremental update and delivery of Data Cubes (compressed aggregated/correlated data) for delivery under under severe bandwidth, processing, and storage constraints
- Developed inference techniques to reason about complex attacks in tactical networks, and forward chaining techniques to detect multi-stage attacks
- Constructed a layered tactical wireless network visualization model for assessing attacks and formulating defensive responses

Dynamic Group Keying

- **Goal is distributed key management algorithms to support dynamic membership despite intermittent connectivity**
- **Developed evaluation criteria for communication, storage, computation for trade-off design and utilization of distributed hybrid keying and authentication for group communications in hierarchical mobile wireless networks**
- **Models that account for hierarchical mobility patterns and use multi-criteria optimization framework**
- **New protocol combines conference and identity-based group keying to conserve energy through reduced communications overhead**

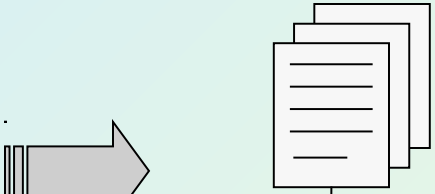


Other Accomplishments

- Published or submitted for publication more than 60 talks and papers
- Staff rotations
  - 6 between ARL and consortium
  - 4 within consortium
- HBCU/MIs participation
  - Involved in 9 of 12 research tasks
  - One co-PI from CCNY
- Thematic workshops
  - Held workshop on Secure Group Communications with 40 attendees (13 March 2002)
  - Workshop on Orthogonal Frequency Division Multiplexing planned for 3Q02
  - Workshop on mobile networking protocols planned for 4Q02
- Awarded two technology transition contracts
  - Optical Sensor Networking for Laser Communications and Atmospheric Channel Characterization (U. Maryland)

APP Planning Process

- Army Vision
- Objective Force
- Army S&T Plan
- ARL S&T Plan
- Other CTA plans
- External research
- Other technology advances
- ....



New and Renewal Proposals

AIs, PIs, TALs

CMC

Evaluation of Existing Program Results & New Proposals

RMB

Collaborative Opportunities
Research Goals
Facilitate Transitions

ARL Approval

Execute

Identify Transition Candidates

TTWG

Technology Transition (6.2) Program

Research Products
- Journal Papers
- Conference Presentations
- Thematic Workshops
- Annual Symposium
- Proof-of-Concept Prototypes

FY03 Annual Program Plan

- **Task-level reviews**

	Date	Location		Date	Location		Date	Location		Date	Location
Task 1.1	20-Mar	UDel	Task 2.1	18-Mar	BAE	Task 3.1	28-Mar	UDel	Task 4.1	14-Mar	NAI
Task 1.2	19-Mar	UMd	Task 2.2	25-Mar	Telcordia	Task 3.2	28-Mar	UDel	Task 4.2	15-Mar	MSU
Task 1.3	4-Mar	UDel	Task 2.3	8-Mar	ARL	Task 3.3	27-Mar	UDel			
Task 1.4	6-Mar	Telcordia		26-Mar	ARL	(all TA 3)	27-Mar	UDel			

- **FY03 planning meetings**
  - **10 April @ ARL (Annual Symposium)**
  - **11-12 April @ University of Maryland**
  - **16-17 April (ARL Division review)**
- **FY03 proposals due to CMC – 1 July**
- **RMB review of FY03 APP – week of 26 August**

Communications and Networks Collaborative Technology Alliance

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